UNPOLARIZED POSITRON SOURCES USING CHANNELING FOR FUTURE COLLIDERS

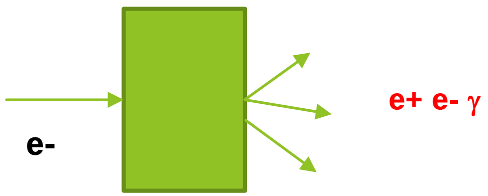
R.Chehab, I.Chaikovska, H.Guler (LAL), X.Artru, M.Chevallier (IPNL), L.Rinolfi, P.Sievers (CERN), K.Furukawa, T.Kamitani, F.Miyahara, T.Suwada, M.Satoh, Y.Seimiya, K.Umemori (KEK), P.Martyshkin (BINP)

UNPOLARIZED POSITRON SOURCES USING CHANNELING FOR FUTURE COLLIDERS

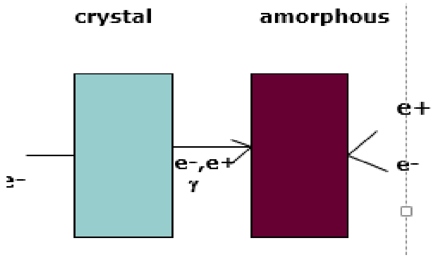
- **INTRODUCTION**
- *** Needs of large photon yields for high level conversion in e+e- pairs**
- *** Interest for low emittance beams➔ high directivity photon beam**
- *** Necessity of decreasing the amount and density of the deposited energy**
- **in the targets**
- **➔ convergent interest towards crystal radiators [radiated energy larger than with classical bremsstrahlung]**

UNPOLARIZED POSITRON SOURCES USING CHANNELING FOR FUTURE COLLIDERS

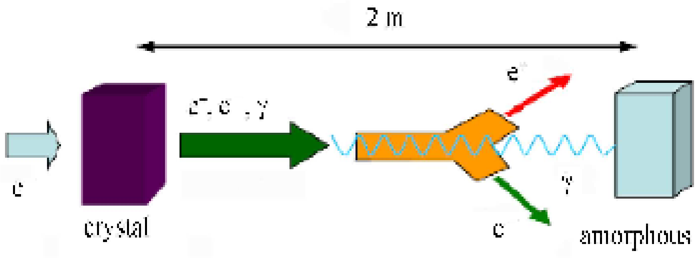
- **THE POSITRON SOURCE USING CHANNELING: A REVIEW**
- **# Thick crystals: radiation and conversion in the same target**



- **# Hybrid: thin crystal-radiator & thick amorphous-converter**



- **# Optimized Hybrid : decrease of the deposited energy**
- **by sweeping off e+e- (from crystal)**



UNPOLARIZED POSITRON SOURCES USING CHANNELING FOR FUTURE COLLIDERS

- **Advantages of the (optimized) hybrid source:**
- **# Thin crystal ➔ higher enhancement γ/e-**
- **➔ less energy deposition ➔ less heating ➔ higher potentials**
-
- **#Thick amorphous converter: high conversion γ ➔ e+ e-**
- **# Distance between radiator and converter ➔ use sweeping magnet to sweep off e+e- from the crystal ➔ less energy deposition and weaker density: avoids high values of PEDD (Peak Energy Deposition Density)**

UNPOLARIZED POSITRON SOURCES USING CHANNELING FOR FUTURE COLLIDERS

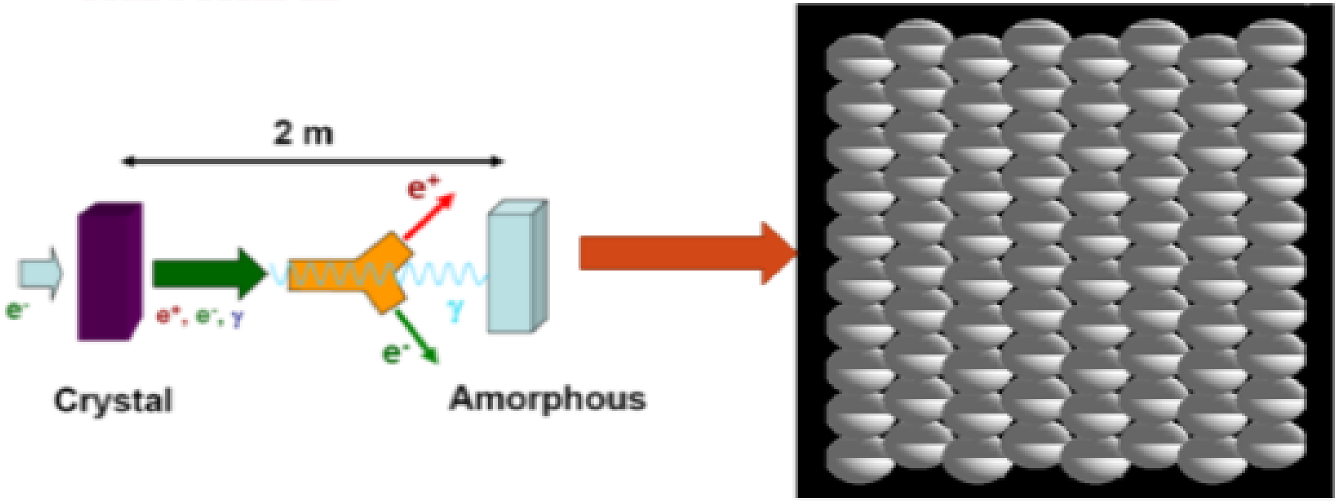
- HYBRID SOURCE PARAMETERS
- # Thickness of the crystal: optimum thickness is between 1-2 mm for E-≤ 10 GeV
- (higher values ➔ saturation)
- # Thickness of the amorphous (high Z material): compromise between the requested yield and the amount of deposited energy; what is essential is the accepted yield.
- # Distance between the radiator and converter:
- => installation of a sweeping magnet
- => increase the size of the photon beam
- ➔ contribute to lower the deposited energy and its density
- # Incident energy: some GeV (to get U_{ch}>> U_{bremss}): U, energy radiated
- # Crystal kind and orientation: W: high atomic potential (1keV) at <111> orientation

UNPOLARIZED POSITRON SOURCES USING CHANNELING FOR FUTURE COLLIDERS

- **AMORPHOUS CONVERTER OPTIMIZATION: FROM COMPACT TO GRANULAR**

3- THE HYBRID SOURCE WITH GRANULAR CONVERTER

- THE SCHEME



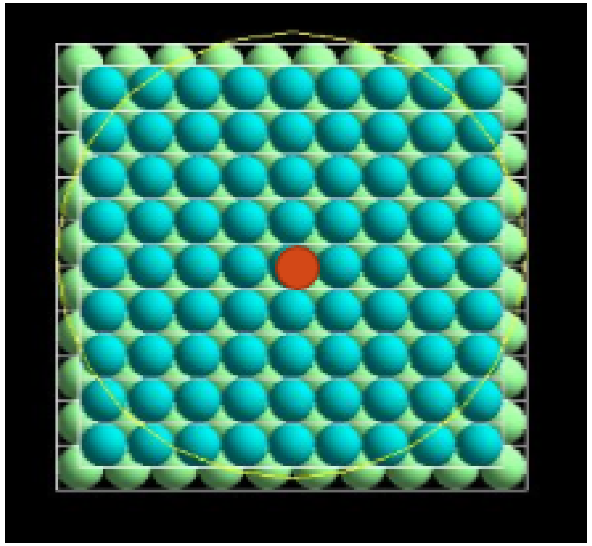
W spheres are put into staggered layers with alternating even and odd numbers. A target is made of a set of couples of 2 layers: the first with even numbers and the second with odd numbers. That allows to have a central sphere on the axis on the last layer, which is the exit face of the converter.

ADVANTAGE OF THE GRANULAR CONVERTER ➔ better heat dissipation

UNPOLARIZED POSITRON SOURCES USING CHANNELING FOR FUTURE COLLIDERS

GRANULAR CONVERTERS: 4 converters have been built (LAL) and some tested at KEK

- * One with 2 staggered layers (10x10
- and 9x9 spheres),
- * One with 4 staggered layers,
- * one with 6 staggered layers
- * one with 8 staggered layers
- The energy deposition is calculated in
- each sphere. The entrance face w.r.t.
- the photon beam has 10x10 spheres;
- the exit face has 9x9 spheres, presenting
- a central sphere on the axis (probable maximum heating). From the energy deposited in this central sphere we could derive the PEDD (approximation)



UNPOLARIZED POSITRON SOURCES USING CHANNELING FOR e+e- COLLIDERS

- **THE ALL CRYSTAL POSITRON SOURCE**
- **(a) WA 103 (CERN) :**

Positron production In a 4 mm W crystal oriented on its <111> axis presented high enhancement (4) ./. amorphous. However, the deposited power in the crystal must be lowered

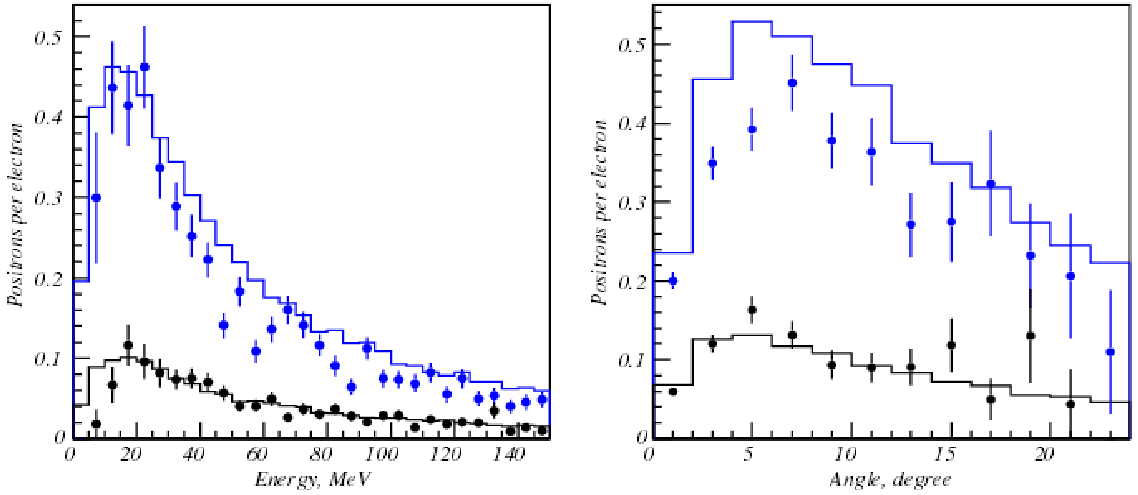


Fig. 11. The positrons horizontal momentum p_h (left) and angular (right) distributions for one incident electron and 4 mm thick target. The electron energy is 10 GeV. The points with error bars are the experimental data. The histograms are the simulated spectra. The upper histograms and points on the plots correspond to the aligned crystal, the bottom histograms and points to the random crystal orientation. These distributions are corrected by the reconstruction efficiency and the detector acceptance.

From NIMB 240 (2005)762

UNPOLARIZED POSITRON SOURCES USING CHANNELING FOR FUTURE COLLIDERS

- **THE HYBRID SOURCE EXPERIMENTS**
- **(b) WA 103 (CERN)**
- **An hybrid W source made of 4 mm crystal <111>**
- **and 4 mm amorphous has been tested at CERN**
- **and compared to a 8 mm crystal; the results**
- **shown on the figure indicate good equivalence**
- **between the 2 options. There is an optimum**
- **thickness < 4 mm. Further calculations indicated**
- **$L_{opt} < 2$ mm.**
- **For future hybrid W sources, at the same incident energy**
- **we shall consider 1-2 mm thick crystals [see ILC, CLIC]**

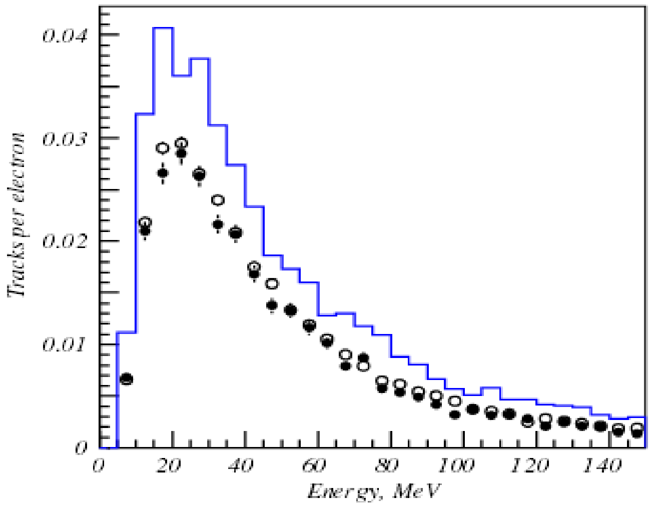


Fig. 12. The positrons energy spectra for the 1 kG magnetic field normalised per 1 incident electron. The spectra are not corrected by the reconstruction efficiency and the detector acceptance. The dark points represent the 8 mm crystal target. The open points, the "4 mm crystal target + 4 mm amorphous target". The histogram is the 8 mm crystal simulation. The electron energy is 10 GeV.

From NIMB 240 (2005) 762

UNPOLARIZED POSITRON SOURCES USING CHANNELING FOR FUTURE COLLIDERS

- **HYBRID SOURCE WITH DIFFERENT CRYSTAL MATERIALS**
- **(c) Experiment at KEK**
- Si, C(d) and W crystals associated to W
- bulk amorphous converters have been tested
- at KEK. The enhancements in e+ w.r.t BH
- are shown for different crystals.
- The references for the crystals are:

Table 1
Specification of the tested crystals

Crystal	Thickness [mm]	Radiation length $[X_0]^a$
Diamond	4.57	0.0372
Silicon1	9.9	0.106
Silicon2	29.9	0.319
Silicon3	48.15	0.514

[a] $1X_0 = 123$ mm for diamond and $1X_0 = 93.6$ mm for silicon.

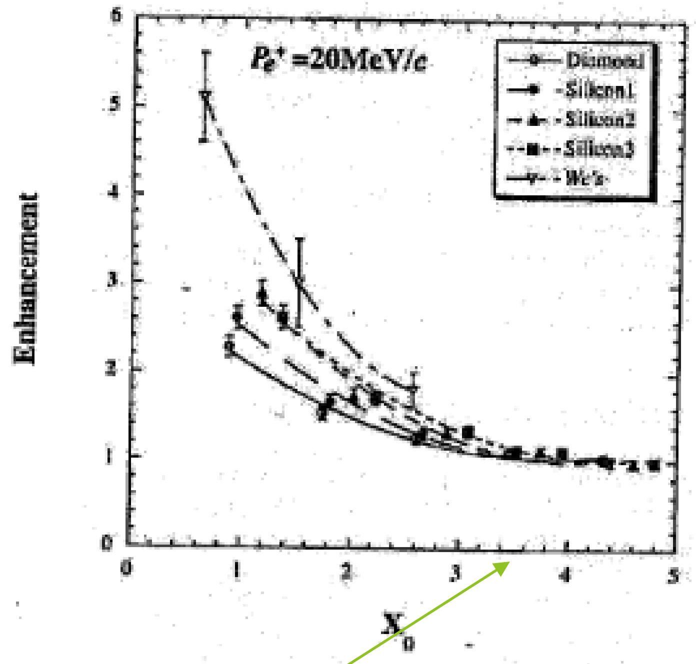


Figure 13. Positron yield enhancements for the combined targets of KEK.

Overall length (Xtal+Am)

M.Satoh et al. NIMB 227(2005)3-10

UNPOLARIZED POSITRON SOURCES USING CHANNELING FOR FUTURE COLLIDERS

- **THE HYBRID SOURCE WITH GRANULAR CONVERTER: TEST AT KEK**
- **THE LAY-OUT**

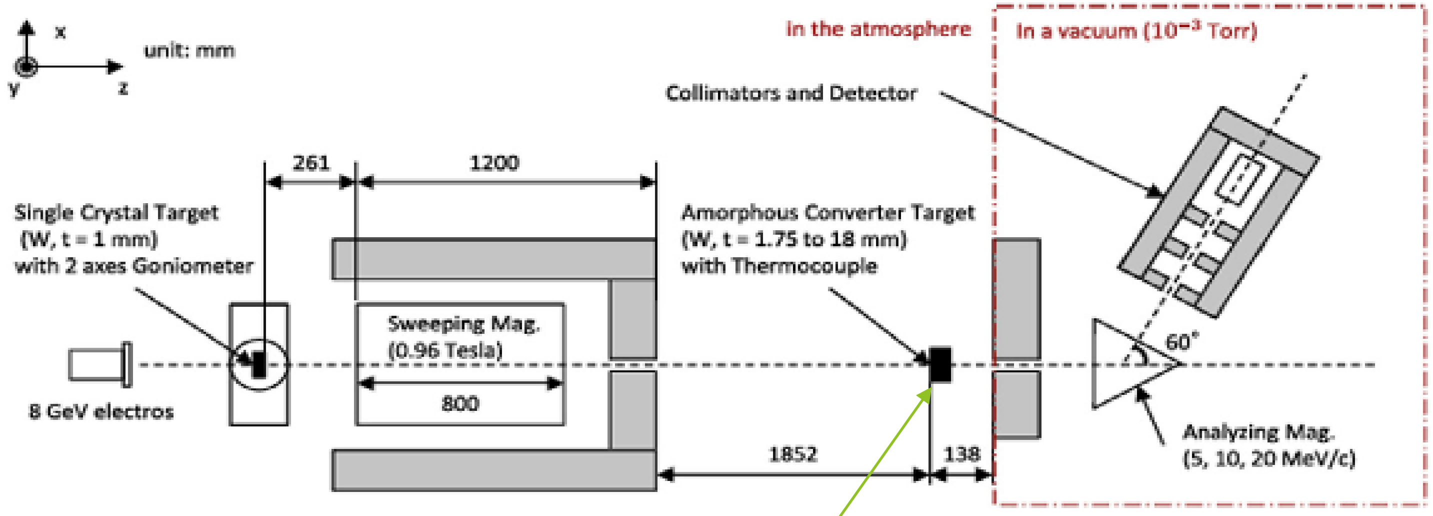


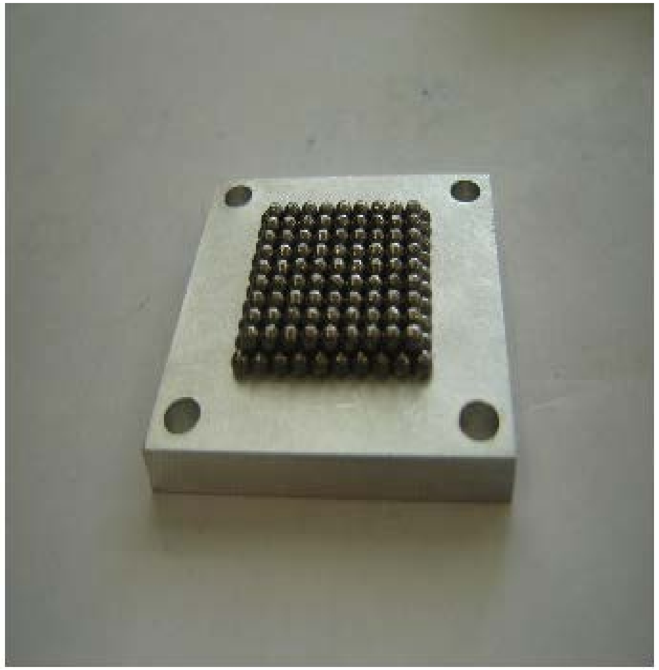
Fig. 6. Lay-out of the hybrid source test at KEK (from Y. Uesugi et al. NIMB **319** (2014)17).

On the place of "amorphous converter target" ➔ compact or granular targets

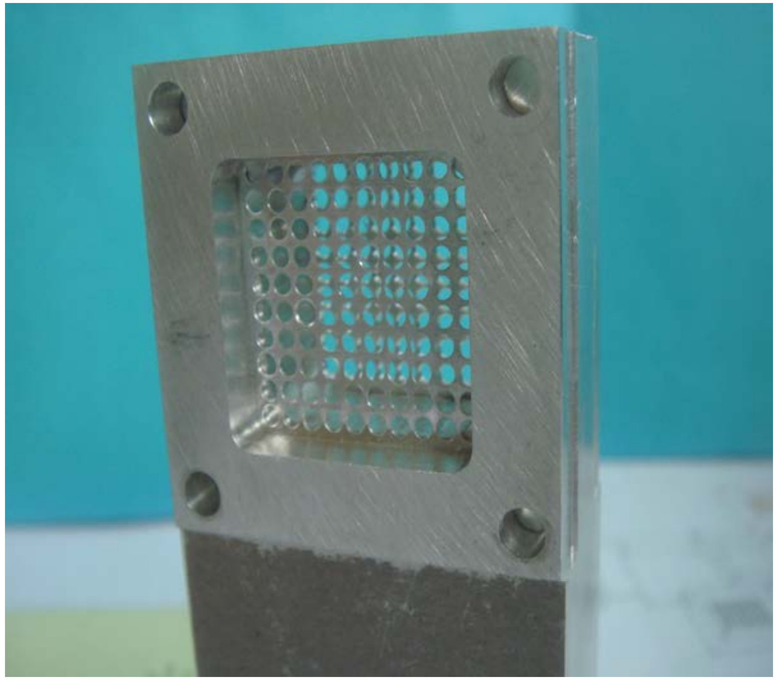
UNPOLARIZED POSITRON SOURCES USING CHANNELING FOR FUTURE COLLIDERS

- **TEST OF THE HYBRID/GRANULAR SOURCE AT KEK: THE CONVERTERS**

STAGGERED W SPHERES LAYERS



MOUNTING FRAMES (Al) : diam. holes <2 mm



UNPOLARIZED POSITRON SOURCES USING CHANNELING FOR FUTURE COLLIDERS

- TEST OF THE HYBRID/GRANULAR SOURCE AT KEK: EXPERIMENTAL CONDITIONS
- * EXPERIMENTAL CONDITIONS:
- E-=7 GeV; single bunch (f=1 to 50 Hz); q(bunch) = 1-2 nC;
- Emittance (norm)~ 150(H)/63(V) π mm mrad; beam divergence< 0.1 mrad
- Crystal W: 1mm thick, <111> orientation
- Granular targets: 4, 6 and 8 layers; Compact target: 8 mm thick
- All amorphous targets on a translation stage; also for the γ detector
- Temperature rise on the converter :➔ thermocouples

UNPOLARIZED POSITRON SOURCES USING CHANNELING FOR FUTURE COLLIDERS

- DETECTION OF PHOTONS AND POSITRONS:
- * PHOTON DETECTION
- # crystal alignment using photon detector: CVD diamond detector 500 μm thick; electric field 400 V on electrode of diamond for charge collection; other electrode connected to Lecroy scope. Weak interaction efficiency (<1 %) but enough γ rays (>10^{11}). The diamond detector has 4x4 cm^2 dimensions.
- * POSITRON DETECTION
- # after the bending analyzer, Cherenkov Detector (Lucite, 5 mm thick)
- ➔ four values of E+ were chosen: 5, 10, 15 and 20 MeV.
- * TEMPERATURE MEASUREMENT
- # Thermocouples with area <1 mm^2 ; glued on W spheres of the exit layer (with epoxy thermal conductive paste). Dynamical range: 0-100° C.

UNPOLARIZED POSITRON SOURCES USING CHANNELING FOR FUTURE COLLIDERS

- **TEST AT KEK: RESULTS**
- *** ENHANCEMENT IN PHOTON PRODUCTION : ROCKING CURVE**
- **Using the photon detector (diamond)**
- **a 2D angular scan provided the rocking**
- **curves, on which the crystal alignment**
- **is based. The enhancement is slightly**
- **larger than 2.**

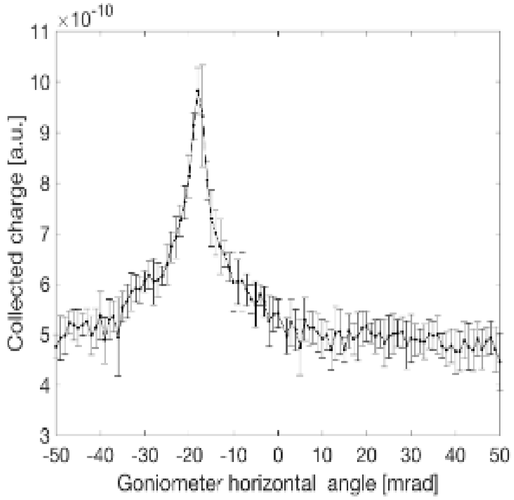
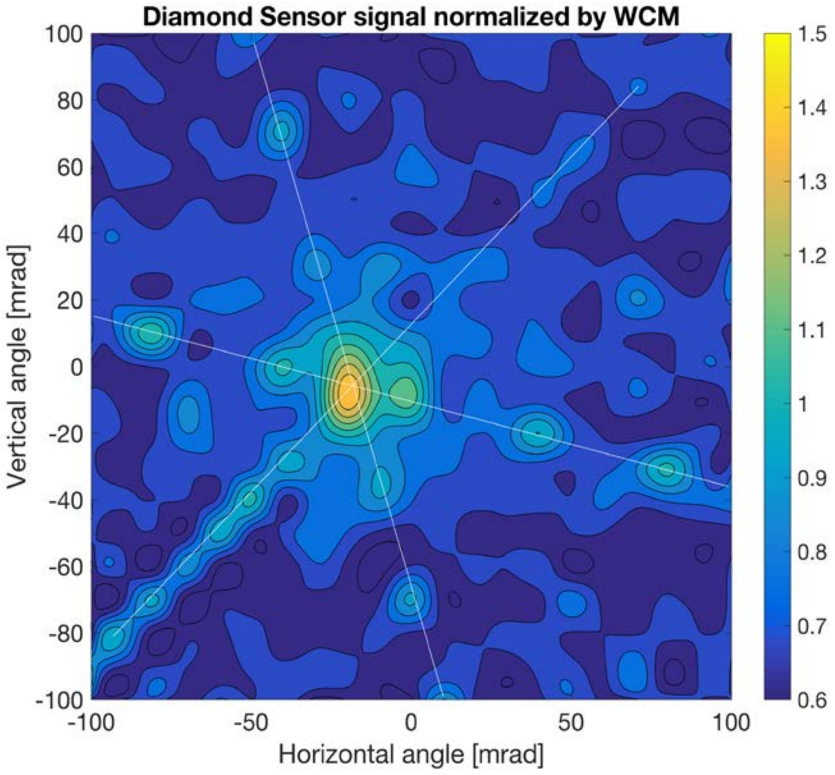


Figure 4: Rocking curve measured by the diamond sensor. Collected charge by the diamond sensor is plotted as a function of the goniometer rotational angle.

UNPOLARIZED POSITRON SOURCES USING CHANNELING FOR FUTURE COLLIDERS

- **TEST AT KEK: 2D SCAN FOR THE PHOTON DETECTION**
- **A 2D scan (± 5.7° in θ_x and θ_y)**
- **associated to the diamond detector**
- **allowed observation of different**
- **channeling directions.**
- **The dimensions of the diamond**
- **detector were:**
- *** thickness 500 µm**
- *** transverse dimensions: 4x4 cm^2**



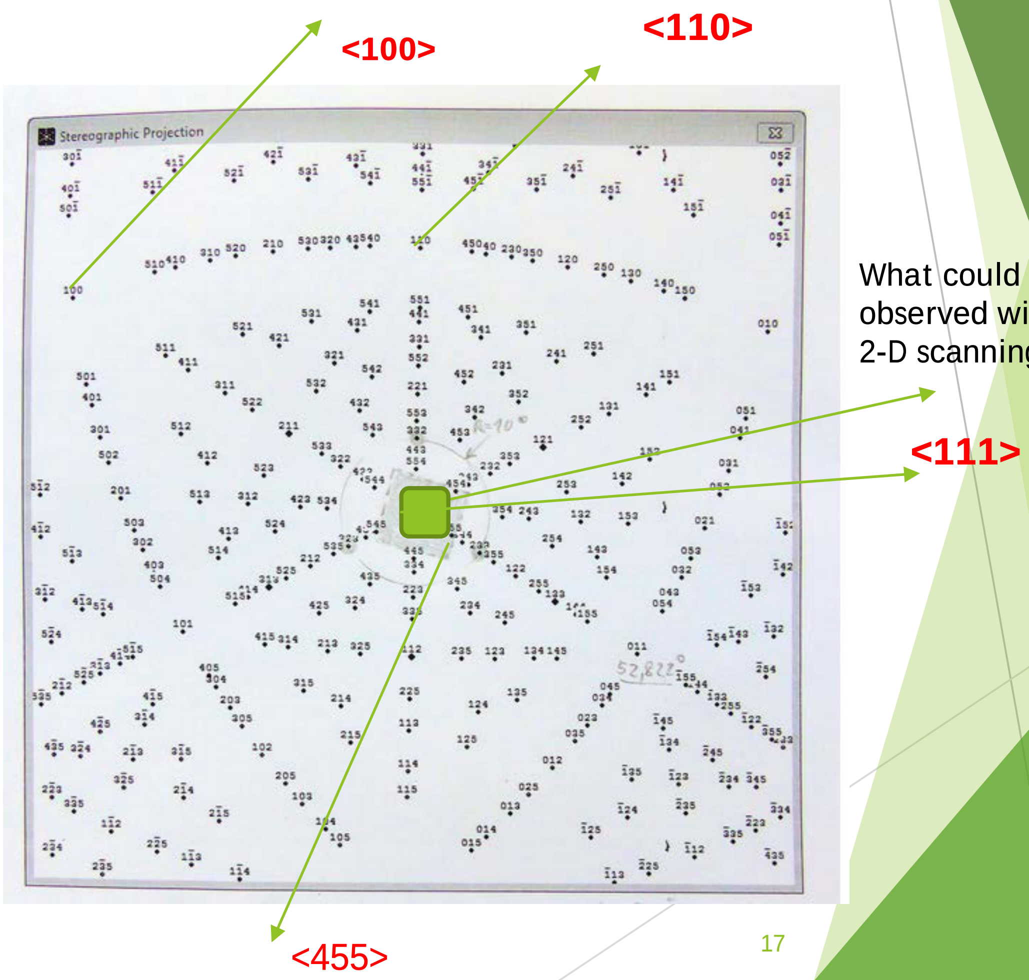
UNPOLARIZED POSITRON SOURCES USING CHANNELING FOR FUTURE COLLIDERS

TEST AT KEK: PHOTON MEASUREMENT

STEREOGRAPHIC PROJECTION

* <110> axis is at 35.2 degrees from <111>
* <100> axis is at 54.7 degrees from <111>
- On the boarder of the detector (in green), the axis <455>

- {comments from Robert Kirsch/IPNL}



What could be observed with 2-D scanning

UNPOLARIZED POSITRON SOURCES USING CHANNELING FOR FUTURE COLLIDERS

- **TEST OF THE HYBRID SOURCE AT KEK**
- **RESULTS ON POSITRONS: POSITRON YIELD**

The positron yield has been measured for 4 values of the positron energy (5, 10, 15 and 20 MeV). Comparisons with simulations have been carried out. On the figure, we show results for a 6-layer granular and a 8 mm bulk converters.

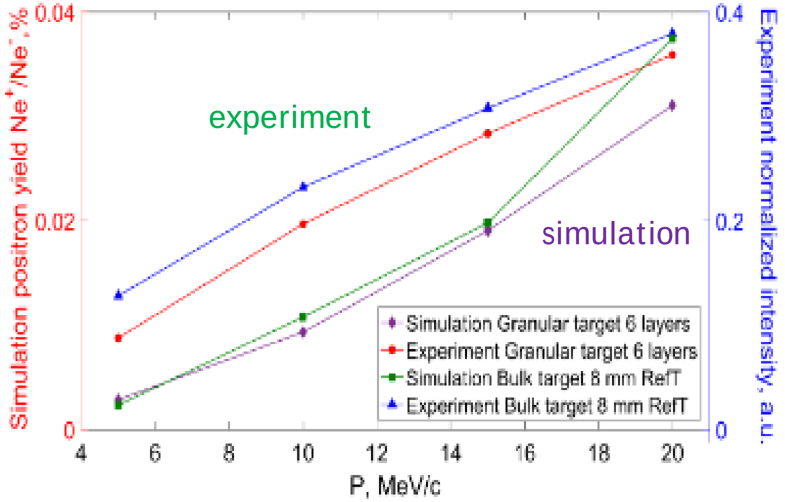
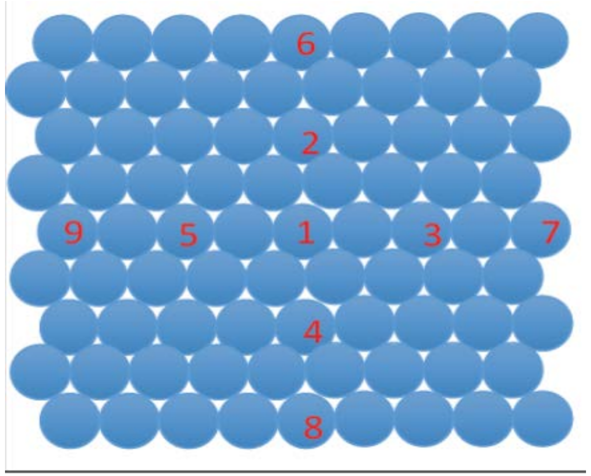
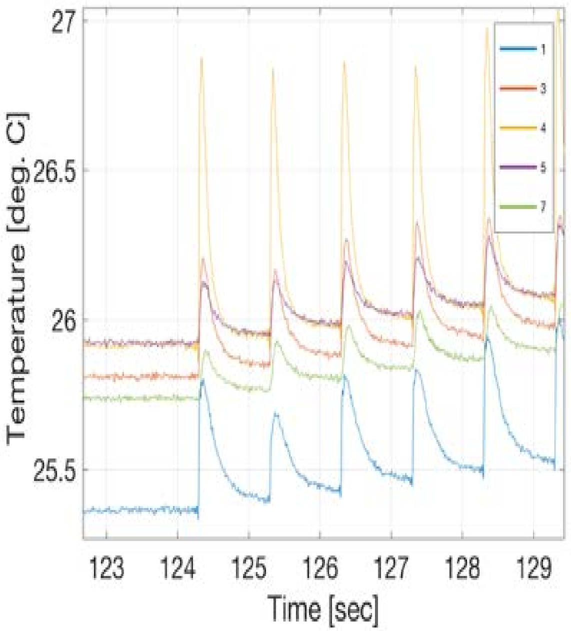


Figure 5: Momentum dependence of the positron yield in the conventional positron production scheme for the 8 mm thick bulk and 6-layers granular targets.

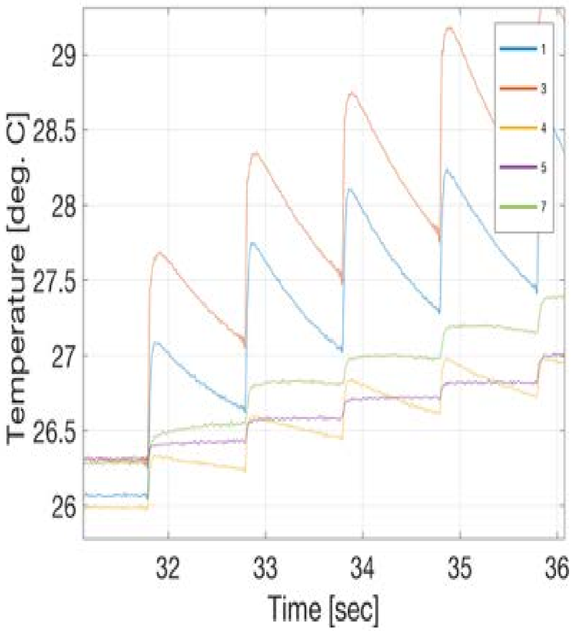
UNPOLARIZED POSITRON SOURCES USING CHANNELING FOR FUTURE COLLIDERS

- **TEST AT KEK: TEMPERATURE MEASUREMENTS**
- **Temperature rise bunch per bunch(1Hz)**
- **on some W spheres and on bulk converter.**
- **Different colours➔Diff. thermocouples.**
- **PEDD derived from the temperature rise**
- **on the central sphere of**
- **the exit face.**





Bulk converter/8mm



Granular 6-layers

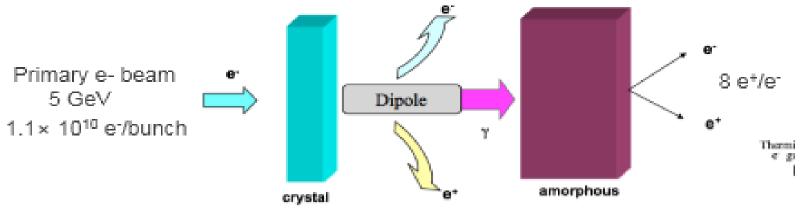
UNPOLARIZED POSITRON SOURCES USING CHANNELING FOR FUTURE COLLIDERS

- **APPLICATIONS TO e+e- COLLIDERS**

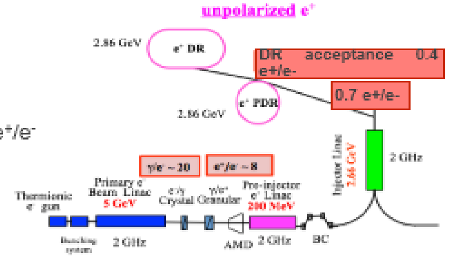
Hybrid scheme

A baseline design for the CLIC positron source

Distance (crystal-amorphous) d = 2 m



Required: 4.3 × 10^9 e+/bunch



Crystal thickness: 1.4 mm
Oriented along the <111> axis

Amorphous thickness: 10 mm

Yield: 8 e+/e- (total) => ~ 1 e+/e- @ 200 MeV => CLIC requirements are fulfilled.

Target Parameters Crystal		
Material	Tungsten	W
Thickness (radiation length)	0.4	χ_0
Thickness (length)	1.40	mm
Energy deposited	~1	kW

Target Parameters Amorphous		
Material	Tungsten	W
Thickness (Radiation length)	3	χ_0
Thickness (length)	10	mm
PEDD	30	J/g
Distance to the crystal	2	m

~ 10 kW
< 35 J/g

UNPOLARIZED POSITRON SOURCES USING CHANNELING FOR FUTURE COLLIDERS

- **2- ILC linear collider**: **The high e- beam intensity is leading to some modifications :**

Considering an application to ILC, we are proposing after T.Omori to modify the beam time structure before the target, (see figure) recuperating the nominal one after the DR. In that case, macropulses with a duration < 1 µs are impinging on the W spheres. Considering the small spheres dimensions, there is a stress relaxation during the temperature rise due to a shock wave propagation shorter than the heating time (~1 µs) . As an example, for the ILC conditions, the radial stress due to a µs pulse is about 10 times lower than for a Dirac pulse. P. Sievers (CERN) is analyzing such effects (see POSIPOL series)

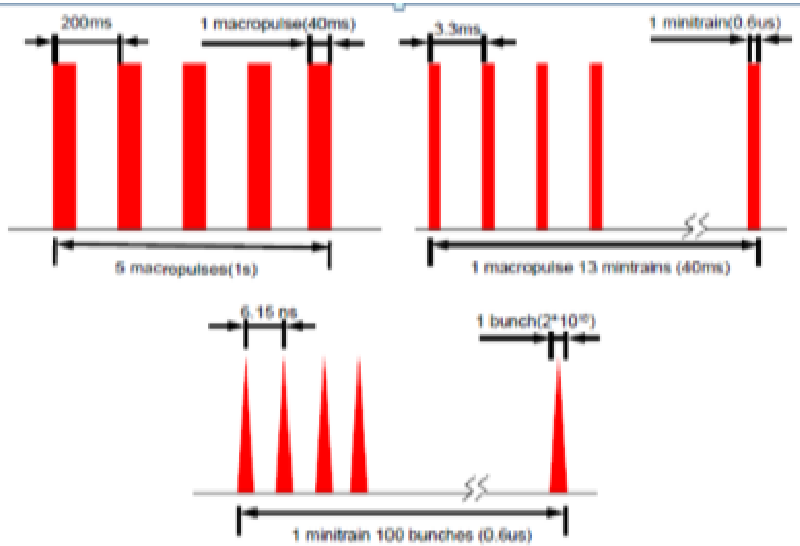


Figure 4.1: ILC beam structure. KEK scheme[42]

Studies on thermal shocks have been carried out by Song Jin (IHEP) and Peter Sievers (CERN).

UNPOLARIZED POSITRON SOURCES USING CHANNELING FOR FUTURE COLLIDERS

- ILC Linear collider: results of simulations
- Granular target: 6 layers
- Total positron yield of
- about ~14 e+/e-
- Deposited energy of ~400 MeV/e-
- Energy deposition density
- of about ~1.4 GeV/cm^3 /e-

W crystal <111>, 1 mm thick
Incident energy: 10 GeV

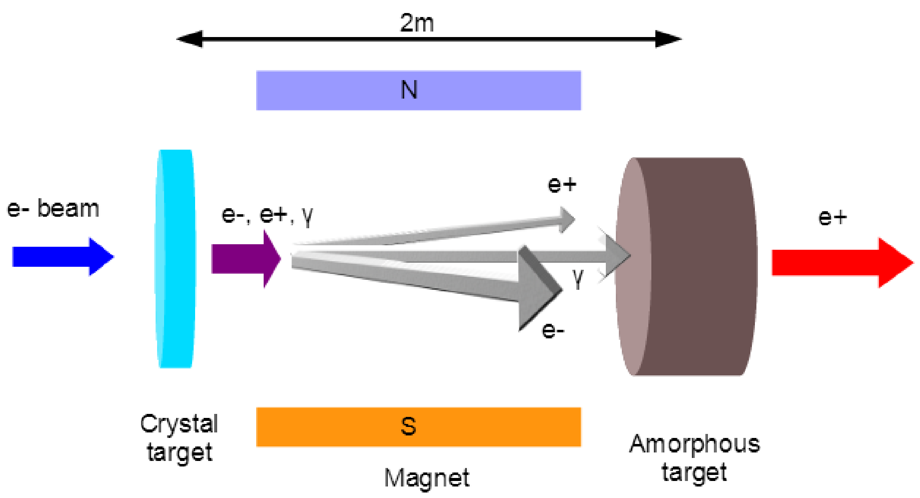
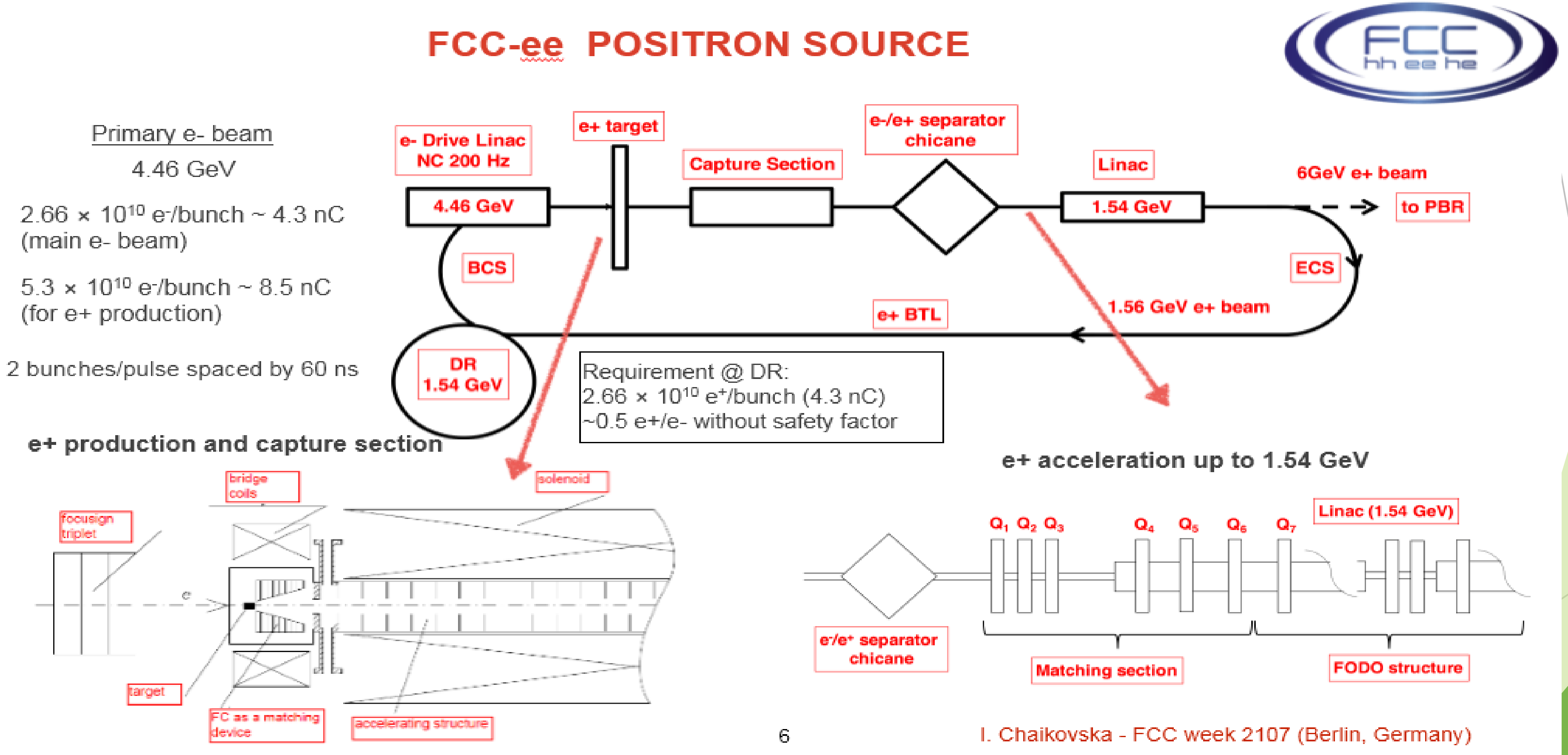


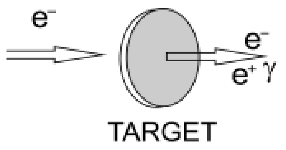
Figure 5.1: Hybrid scheme using crystal and granular target for ILC.

UNPOLARIZED POSITRON SOURCES USING CHANNELING FOR FUTURE COLLIDERS



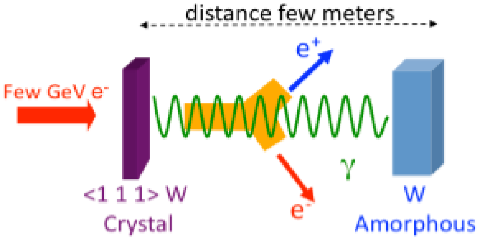
UNPOLARIZED POSITRON SOURCES USING CHANNELING FOR FUTURE COLLIDERS

Positron Sources



1) <u>Conventional positron target:</u> bremsstrahlung and pair conversion

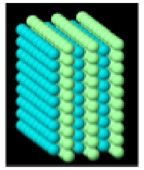
- Classical e+ source.
- It was employed to produce e+ beam at the existing machines (ACO, DCI, SLC, LEP, KEKB…).



2) <u>Hybrid positron target:</u> Two-stage process to generate positron beam. Channeling (crystal target) and pair conversion (amorphous target)

- Use the intense radiation emitted by high energy (some GeV) electrons channeled along a crystal axis => *channeling radiation*.
- Charged particles are swept off after the crystal target => the deposited power and PEDD (Peak Energy Deposition Density) are strongly reduced.
- Granular target can provide better heat dissipation associated with the ratio Surface/Volume of the spheres and the better resistance to the shocks.

Recent idea: to replace the bulk target-converter by a **granular** one made of **small spheres**.



Several experiments had been conducted to study the hybrid e+ source (proof-of-principle experiment in Orsay, experiment @ SLAC, experiment WA 103 @ CERN and experiments @ KEK).

01/06/2017 Granular target-converter 5 I. Chaikovska - FCC week 2107 (Berlin, Germany)

UNPOLARIZED POSITRON SOURCE USING CHANNELING FOR FUTURE COLLIDERS

A SOLUTION FOR FCC-ee BASED ON CLIC SOURCE

Hybrid scheme

- **Flux Concentrator (FC):** peak field is 6 T, DC solenoid field is 0.5 T, length = 20 cm, aperture 40 mm.
- **Accelerating structures:** L-band 2GHz, 25 MV/m, aperture 30 mm.

	@ 200 MeV	@ 2.86 GeV
e+ yield, Ne+/Ne-	0.98	0.97
Emittance norm, µm rad	9	9

☞ CLIC e+ source design seems compatible with the FCC-ee requirements => optimisation with FCC-ee beam parameters.

UNPOLARIZED POSITRON SOURCES USING CHANNELING FOR FUTURE COLLIDERS

- A COMPARISON BETWEEN THE TWO OPTIONS: CONVENTIONAL/HYBRID
- General conditions; E-=5 GeV; σ^- =2.5 mm; bunch q = 8.5nC; pulses of 2 bunches at 200 Hz; beam power: 15 kW.

Kind of source	Deposited energy	PEDD
Conventional 4.5 Xo	2.7 kW (17%)	2.1 J/g
Hybrid-Compact	1.2 kW (8 %)	1 J/g
Hybrid-Granular(6-layers)	0.85 kW	0.6 J/g

- For the sake of comparison the incident electron energy has been taken as 5 GeV instead of 4.46 GeV, due to available results at 5 GeV.

UNPOLARIZED POSITRON SOURCES USING CHANNELING FOR FUTURE COLLIDERS

- **PRELIMINARY CONCLUSIONS**
- *** The hybrid positron source using channeling to enhance photon generation and henceforth positron production has been investigated and experimented successfully at CERN and KEK. Its use in linear colliders, where the high intensity is a challenge, can be considered, as shown for CLIC where it has been chosen as the baseline. For ILC, its remains an interesting solution because the deposited energy in the converter as the PEDD are lower than the equivalent (same yield) conventional scheme. A cooling system for both the crystal and the converter are foreseen. Concerning the circular colliders, as FCC-ee, even if the deposited energy and the PEDD are much less a problem because of the lower intensity, it presents still an advantage for these two parameters with respect to the conventional solution.**

UNPOLARIZED POSITRON SOURCES USING CHANNELING FOR FUTURE COLLIDERS

BACK-UP SLIDES

UNPOLARIZED POSITRON SOURCES USING CHANNELING FOR FUTURE COLLIDERS

- **RADIATION DAMAGE TEST AT SLAC (1996)***
- **In order to study the radiation damages on the W crystal, a thin crystal (0.3 mm thick) has been installed upstream of the SLC e+ target and irradiated during 6 months. The cumulated fluence was 2.10^{20} e-/cm^2. No damage was observed (same rocking curve after and before irradiation).**
- **FWHM → 0.03° . [Collaboration LAL-IPNL-SLAC-MPI-Stuttgart + LR]**

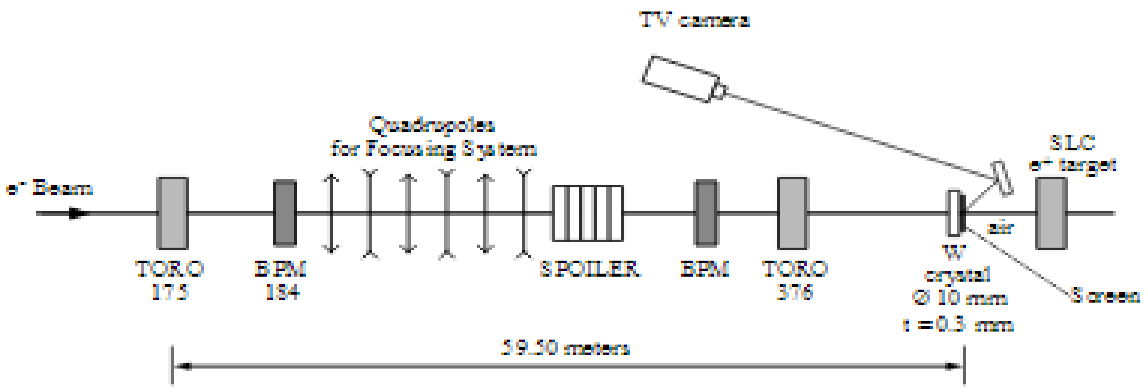
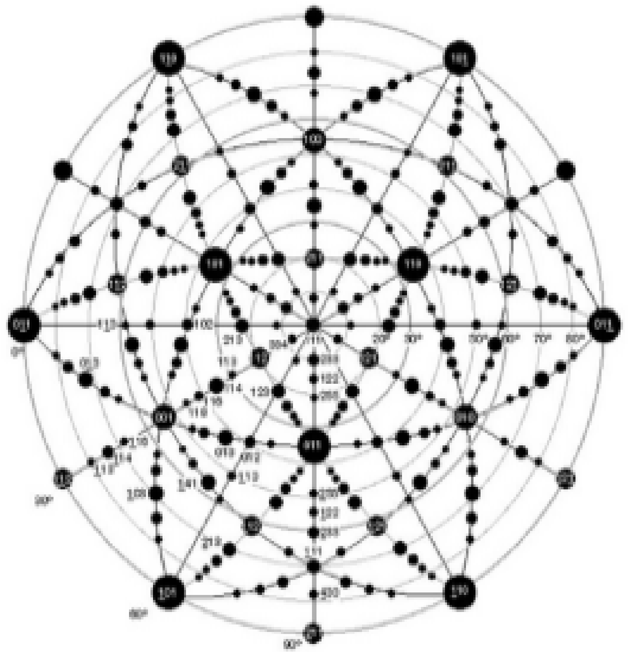


Figure 3: The SLC experimental set-up

UNPOLARIZED POSITRON SOURCES USING CHANNELING FOR FUTURE COLLIDERS

- TEST AT KEK: PHOTON MEASUREMENT
- The main axes of the w crystal are
- represented on this figure with
- concentric circles corresponding
- to different aperture angles (from
- 10 to 10 degrees), the central axis
- being <111>.

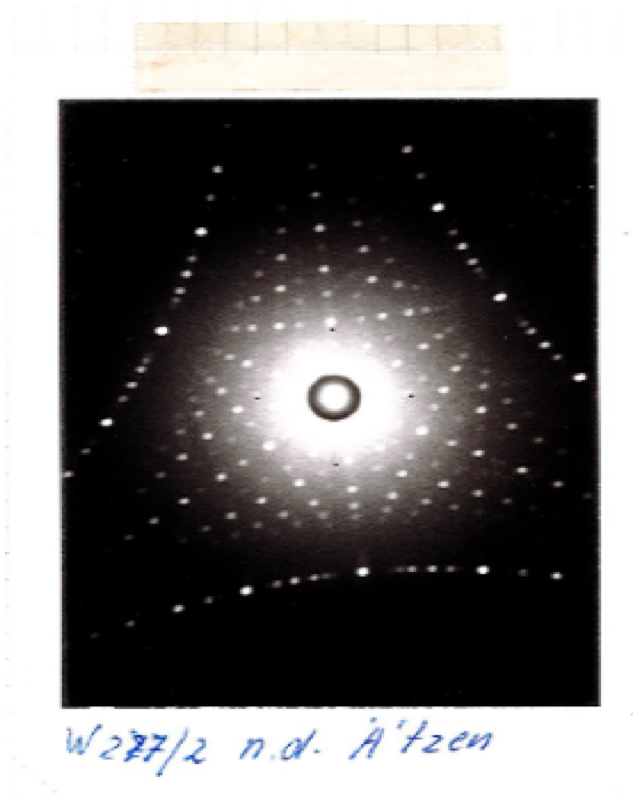


R.Chehab/POSIPOL2017/BINP

UNPOLARIZED POSITRON SOURCES USING CHANNELING FOR FUTURE COLLIDERS

W CRYSTAL AXES

Measurements operated at the Max-Planck Institute of Stuttgart on a thin 0.3 mm) W crystal oriented on its <111> axis using a X beam (Laue diagram)



R.Chehab/POSIPOL2017/BINP